Nitrogen Isotope Evidence for Manuring of Early Neolithic Funnel Beaker Culture Cereals from Stensborg, Sweden

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Abstract

Little is known about arable agriculture in the Early Neolithic (4000–3300 cal BC, Funnel Beaker Culture) of Southern Scandinavia. Archaeobotanical material is rare and few archaeological sites have yielded more than a small number of charred cereal grains. In this short communication, we present single-entity carbon and nitrogen isotope analyses of charred cereals from Stensborg, an early Funnel Beaker Culture site near Stockholm, Sweden. This cereal assemblage is important as it is large, well-preserved and consists of multiple crop species. Our isotopic results indicate that many of the Stensborg cereal crops had been manured and that there is intra- and inter-species variation in manuring. We interpret these data as evidence of an integrated regime of stock-keeping and small-scale agriculture in the early Funnel Beaker Culture near its northernmost limit.

1.0 Introduction

Farming practice in the first 700 years of the Funnel Beaker Culture (Early Neolithic, 4000–3300 cal BC, TRB) of the Scandinavian Neolithic is not well understood. Recent research has addressed movement, feeding environments, and birth season manipulation in domestic cattle in this period (Gron et al., 2015, 2016; Gron and Rowley-Conwy, 2017) but the evidence for arable agriculture is limited. Cultivation is suggested by the presence of several species of cereal, including emmer wheat (*Triticum dicoccum* (Schrank) Schübl), einkorn wheat (*Triticum monococcum* L.), naked barley (*Hordeum* sp. var. nudum) and bread wheat (*Triticum aestivum* L.) (Robinson, 2003; Hallgren, 2008; Kirleis et al., 2012), and by the presence of plough-marks below earthen long barrows (Beck, 2013). Therefore, while a century of research has fed a persistent debate regarding the underlying drivers of the origins of agriculture in the region (see Madsen et al., 1900; Fischer and Kristiansen, 2002; Andersson et al., 2016; Price, 2016), our basic understanding of the actual agricultural practices being employed is still limited. For example, whether animal manure was applied to crops prior to the Bronze Age is still debated (Bakels 1997; Gustafsson 1998; Grabowski 2011).

In this short communication, we present carbon and nitrogen isotope analysis of three species of domestic cereals (emmer wheat, naked barley and bread wheat) from the Early Neolithic (hereafter EN) Funnel Beaker Culture (Swedish *Trattbägarkultur*, hereafter TRB) site at Stensborg, near Stockholm, Sweden. This assemblage represents one of the largest collections of carbonised cereals from Scandinavia during this early period. The site is located in one of the most northerly areas of the TRB North Group (Figure 1; Hallgren, 2008; Müller, 2011; Sørensen, 2015) and the assemblage presents an opportunity for understanding early Neolithic northern European cultivation near its geographic, cultural and economic limits.

2. Methodological Context, Materials and Methods

2.1. Stable isotope research in archaeobotany

Carbon and nitrogen isotopic analysis of charred plant remains is a relatively new application in archaeological science and a series of studies have shown its research potential for identifying the application of manure to increase productivity in cereals, recognized through higher $\delta^{15}N$ values (Bol et al., 2005; Bogaard et al. 2007, 2013; Fraser et al., 2011, 2013; Kanstrup et al., 2011, 2012, 2014; Fiorentino et al., 2012; Nitsch et al., 2015). At present, the only available data of this type from the EN in southern Scandinavia consists of the bulk analysis of five naked barley grains from Frydenlund, Funen, Denmark (Kanstrup et al., 2014). This data was reported but not interpreted on the basis of divergence from the main dataset.

Cereal grains must be charred at or above 220°C to carbonize effectively (Styring et al., 2013; Charles et al., 2015) and this may produce an offset in the isotope values from the carbonised grains compared to the fresh grains. However, there is some debate as to the extent of the effect of charring on $\delta^{13}C$ and $\delta^{15}N$, mostly dependent on the thermal conditions and the duration of firing (Kanstrup et al., 2012; Bogaard et al., 2013; Fraser et al., 2013; Styring et al., 2013). $\delta^{13}C$ values are minimally or not affected (Fiorentino et al., 2012; Fraser et al., 2013). In contrast, $\delta^{15}N$ may be affected to a greater extent by charring, raising values above those on uncharred grains. Fraser et al. (2013) suggest that charring raises $\delta^{15}N$ values by 1 ‰, and this correction was applied by the pan-European study of Bogaard et al. (2013). Recent research has shown that the actual offset may be smaller and it is suggested by Nitsch et al. (2015) that a value of 0.31 ‰ be subtracted from data obtained on charred cereals to obtain a likely value for the material prior to charring.

Bogaard et al (2013) identified manuring intensity based on ranges of cereal $\delta^{15}N$ values from long-term agricultural experiments and applied three levels of manuring (none or low <3.0 ‰ $\delta^{15}N$; medium 3.0-6.0 ‰ $\delta^{15}N$; high >6.0 ‰ $\delta^{15}N$) to bulk samples of Neolithic cereal remains from across Europe. Nitrogen cycling between soil and plants is a complicated system that varies over time and space and manuring is not the only mechanism for raising nitrogen levels in soil. However, it is very difficult to directly measure the nitrogen levels (and $\delta^{15}N$) in European soils of the mid-Holocene, as very few contemporary palaeosols exist in the archaeological record and those that do exist are likely to have experienced post-depositional chemical alteration. This makes direct comparison and quantification problematic. For example, there are no contemporary mid-Holocene palaeosols analysed in the region around Stensborg and we do not know the baseline nitrogen values in the soils of the woodland clearings that were the likely focus for early cereal agriculture in the region. However, a recent isotopic analysis of wild woodland herbivores in the Mesolithic and Neolithic of southern Scandinavia (Gron & Rowley-Conwy 2017), which also reviewed the existing literature, demonstrated that the highest $\delta^{15}N$ values in the bone collagen of these herbivores was 6.1 ‰ (Craig et al. 2006), with average values much lower at ca. 4.5 ‰. It is therefore reasonable to assume that the forest plants consumed by the herbivores were a trophic level (very conservatively estimated at 3 ‰) lower than these values (Bocherens and Drucker 2003), placing all but the absolute highest soils within the 'none to low' range of manuring intensity identified by Bogaard et al (2013), and more than likely lower. Therefore, we have chosen to apply the $\delta^{15}N$ manuring ranges outlined by Bogaard et al (2013) to our data, mindful of the interpretive caveats that do exist.

2.2. The study site of Stensborg

Stensborg is located ca. 25 kilometers south-west of the centre of what is today Stockholm, just south of the community of Tumba in Stockholm County (Figure 1). In the Neolithic, the site was located adjacent to a deep bay, and enclosed on the other three sides by several streams and a ridgeline. Archaeological material was first identified by an unusual number of surface finds of broken and/or burned lithics, and subsurface excavations uncovered a series of pits containing objects, some originating from hundreds of kilometers away (Larsson and Broström, 2011, 2014).

Most notable of the subsurface finds were a series of pits in clay, several of which contained thousands of carbonized grains but little crop-processing debris and no weed seeds, indicating careful cleaning prior to burning (Larsson and Broström, 2011, 2014). These three pits, referred to as Pit 1, Pit 2, and Pit 3, contained single pit fills and over a thousand cereal remains each, including emmer wheat, naked barley and bread wheat (quantification in Larsson and Broström 2011: 196). Very little charcoal was found with the archaeobotanical remains and so the archaeobotanical assemblage has been interpreted as being: 1) either deliberately charred grain placed through structured deposition (Richards and Thomas 1984); or 2) the accidently charred remains of the cleaned cereal product becoming incorporated into the pit fills (Hillman 1984).

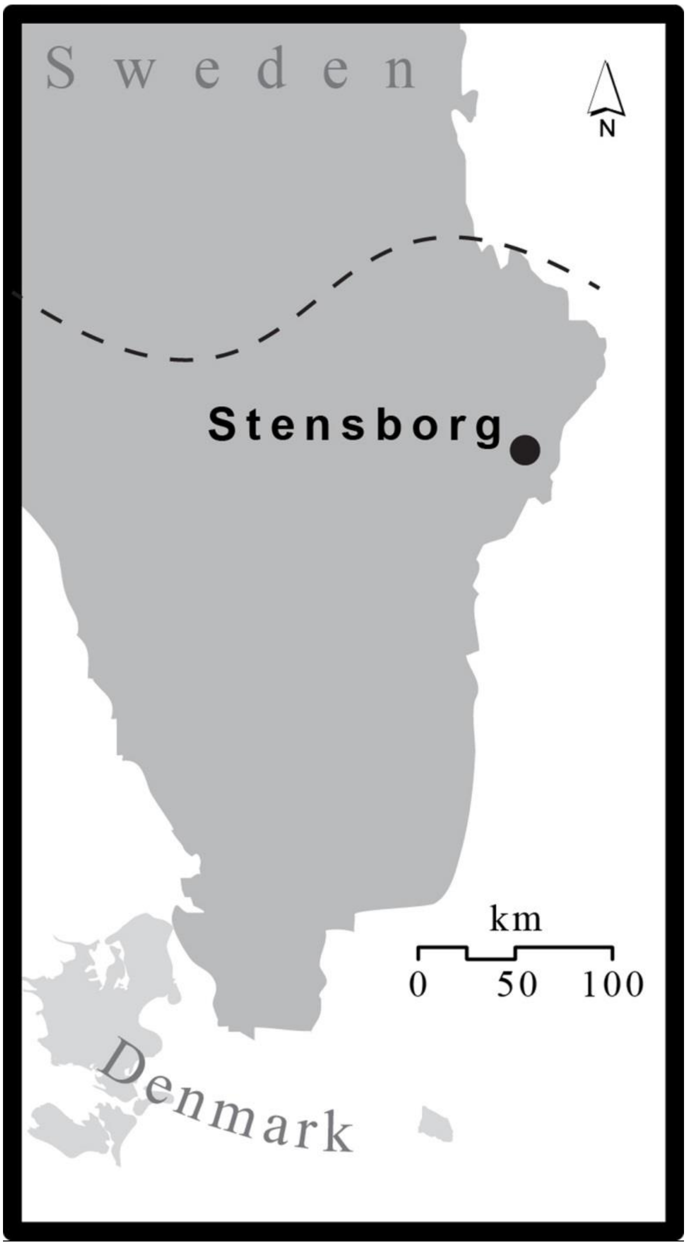

Figure 1: The location of Stensborg in central Sweden. The dotted line indicates the approximate northernmost limit of the TRB North Group (after Hallgren, 2008; Müller, 2011).

Single-entity cereal grains from each pit were AMS radiocarbon-dated (Larsson and Broström 2011) to produce the following dates: Pit 1: 4760±50 bp (LuS-9570), Pit 2: 4710±75 bp (LuS-9571), Pit 3: 4800±50 bp (LuS-9184). Calibrated ranges at 95% confidence (2σ) were obtained using the IntCal13 atmospheric dataset (Reimer et al., 2013) and the OxCal v4.3 calibration program (Bronk Ramsey, 1995, 2001), producing an overlapping date range of 3693–3360 cal BC from the three pits. This spans the transition between the Early Neolithic I (ENI) and the Early Neolithic II (ENII) periods of the Scandinavian early Neolithic (Larsson and Broström 2011, 2014).

2.3 Sampling and analysis of cereals for isotopic research at Stensborg

We undertook a single-grain analytical approach for the following two reasons. Firstly, we wanted to observe the variance between the grains analyzed for each species from each pit. Secondly, we wanted to examine if there were any systematic isotopic offset between grains of differing preservation. In all, 80 carbonized cereal grains were selected for analysis (Supplementary Table 1). Different species were sampled in order to determine any difference in crop husbandry. We chose 10 grains of the best preservation (see below) from each pit, allowing our results to be directly compared to the data produced by recent large-scale grain isotope studies elsewhere in Europe (Bogaard et al., 2013; Kanstrup et al., 2014). From Pit 1 10 individual grains each of naked barley, emmer wheat and bread wheat were selected. From Pit 2, 10 individual grains each of emmer and bread wheat were selected. From Pit 3, 10 individual grains of emmer wheat were selected. Lastly, a mixed sample of a total of 10 grains of naked barley comprised of grains from Pits 2 and 3 were analyzed on account of there being too few individual grains of suitable preservation for analysis from Pit 3 alone.

Well-preserved grains were selected (Hubbard and al-Azm, 1990 preservation grades P2 and P3) in order to ensure accurate identification and to minimize any possible isotopic offset from badly preserved grains produced in higher temperatures (Supplementary Table 1). Samples were then measured in three dimensions, weighed (Supplementary Table 1) and photographed prior to isotopic analysis. Grains were not further processed in any way, save for crushing to a powder. Total organic carbon, total nitrogen content and stable isotope analysis of the samples were performed using a Costech Elemental Analyser (ECS 4010) connected to a Thermo Scientific Delta V Advantage isotope ratio mass spectrometer at Durham University. Carbon isotope ratios were corrected for ^{17}O contribution and reported in standard delta (δ) notation in per mille (‰) relative to Vienna Pee Dee Belemnite (VPDB). Isotopic accuracy was monitored through routine analyses of in-house standards (Glutamic acid, $\delta^{13}C$ = –11.00 ‰, $\delta^{15}N$ = –7.50 ‰; Urea, d13C = –44.00 ‰, $\delta^{15}N$ = 0.00; Spar Calcite, $\delta^{13}C$ = +2.90 ‰), which were stringently calibrated against international standards (e.g., USGS40, USGS24, IAEA-600, IAEA-N-1, IAEA-N-2): this provided a linear range in $\delta^{13}C$ between –44 ‰ and +3 ‰ and in $\delta^{15}N$ between –7.5 ‰ and +20.4 ‰. Analytical variation in carbon and nitrogen isotope analyses was typically ±0.1 ‰ for replicate analysis of the international standards and typically <0.2 ‰ on replicate sample analysis. Total organic carbon and nitrogen data was obtained as part of the isotopic analysis using an internal standard (Glutamic Acid, 40.82 % C, 9.52 % N).

3. Results and Discussion

Eighty carbon and nitrogen isotope values were obtained on the individual cereal grains from Stensborg. Summary values are presented in Table 1 and individual results in Supplementary Table 1. Overall, percentage carbon and percentage nitrogen values are higher in the Hubbard and al-Azm (1990) preservation grade P2 grains than in grade P3 (%N Student's t-test t=2.4107 $p < 0.05$, %C Student's t-test t=3.4342 $p < 0.01$), although preservation grade does not create a significant difference on overall $\delta^{13}C$ (Student's t-test t= 0.3948 $p = 0.69$)or $\delta^{15}N$ values (Student's t-test t= 1.6894 $p < 0.10$; Supplementary Table 1). We present and interpret the unadjusted $\delta^{13}C$ and $\delta^{15}N$ values. The reason for this is simply that we do not know the duration, atmospheric conditions, or temperature of charring, all of which can affect isotope values (Nitsch et al., 2015). Had we applied the most recent $\delta^{15}N$ correction of 0.31 ‰ (Nitsch et al., 2015), our interpretations would remain unchanged, and we emphasize that the observed differences between species would not be affected. We also have not taken into account any changes in atmospheric CO_2, as suggested by Ferrio et al. (2005) and Bogaard et al. (2013), as all of our data is within the same radiocarbon date range. The discussion below also assumes that the cereals deposited in the three pits at Stensborg originated from crop production with an economic and subsistence purpose.

Pooled mean $\delta^{15}N$ values for emmer wheat, bread wheat, and naked barley across contexts average +3.98 ‰, +4.13 ‰, and +2.69 ‰ respectively. $\delta^{13}C$ values, when pooled similarly for emmer wheat, bread wheat, and naked barley respectively, average –24.88 ‰, –25.25 ‰, and –25.83 ‰. For clarity of visualization, the grains yielding the uppermost and lowermost $\delta^{15}N$ values (and their corresponding $\delta^{13}C$

values) were removed and associated statistics re-calculated (Supplementary Table 2) and plotted with mean and two standard-deviation ranges in Figure 2.

Table 1: Summary Data. Percent of grains in manured range (>3 ‰) as per Bogaard et al. (2013).

δ [13]C values in plants are a direct indicator of the water conditions under which a plant grew. When pooled across all contexts, the average $\delta^{13}C$ values for emmer wheat, bread wheat, and barley are all within 1 ‰ of one-another, within the natural isotopic variation observed in plants grown under the same water regime in experimental studies (Wallace et al., 2013). If $\delta^{13}C$ values are instead averaged by pit and by species (Table 1), the same is true with the only exception of the naked barley from the Pit 2/3 sample (ST IS. 51-60), which is more than 1 ‰ less positive than the others. However, this is a mixed sample and also has the largest variance both in $\delta^{15}N$ and $\delta^{13}C$. Any claims regarding potentially different watering regimes are speculative at best. Therefore, there are no strong grounds for arguing that any of the grains were raised under a different watering regime.

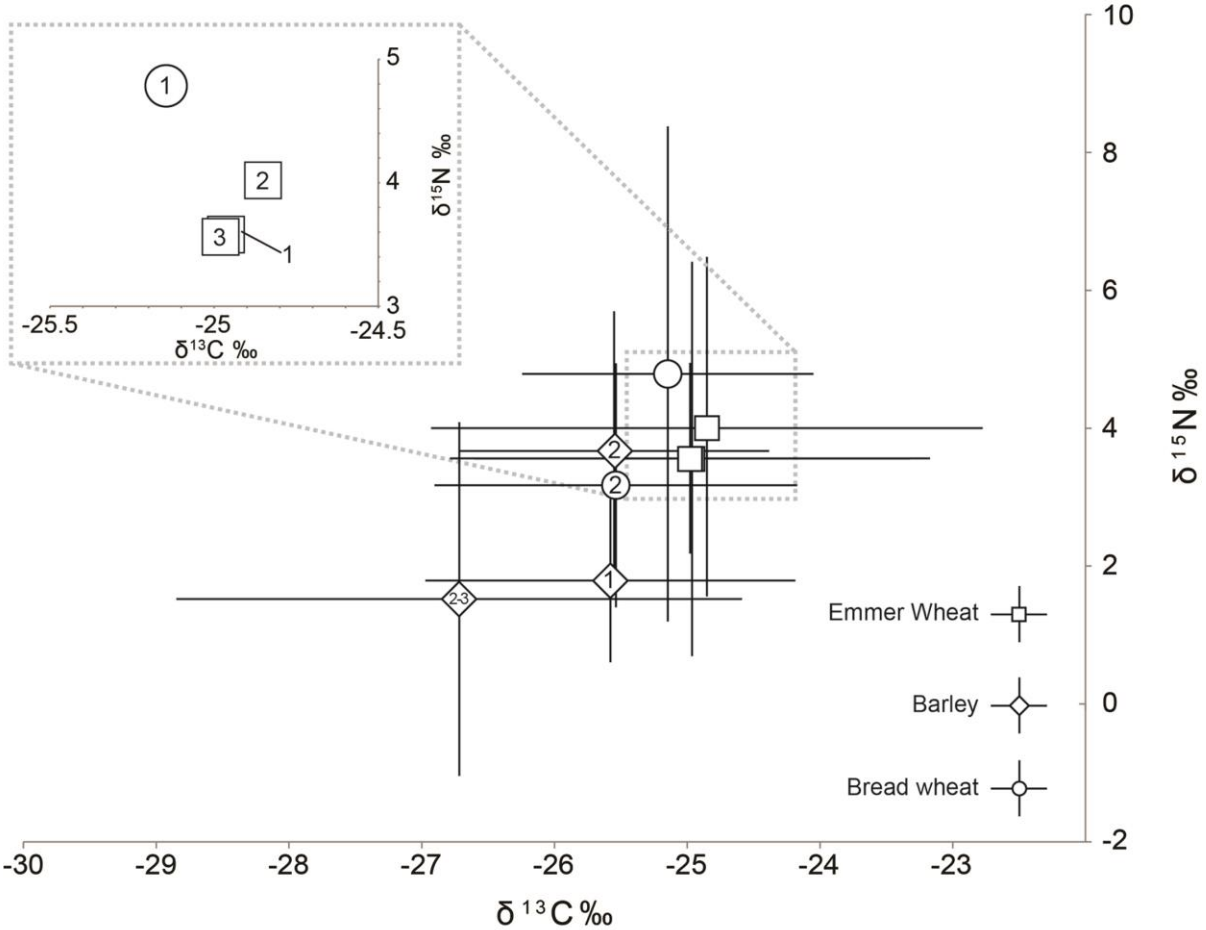

Figure 2: Stensborg cereal isotope results. Shapes indicate species and mean, numbers within the shapes indicate the pit number from which the sample came. Mean and two standard-deviation ranges by species and context calculated omitting grains yielding maximum and minimum $\delta^{15}N$ their associated $\delta^{13}C$. See Supplementary Table 2. Inset for clarity as all emmer wheat averages are very similar.

$\delta^{15}N$ values in the range of ca. 3–6 ‰ are considered indicative of medium (10-15 tons/hectare) manuring of a field under seed (Bogaard et al., 2013). By this measure, averaged values for all emmer and bread wheat grains from individual pits analyzed here and the barley from Pit 2 fall into this range. The averaged values for barley from Pit 1 and the combined sample from Pits 2/3 do not, instead falling in a range characteristic of low or an absence of manuring (Bogaard et al., 2013). The single grain analyses duplicate and reinforce these results by a simple majority in all cases by pit (e.g., if more than half of the analyses have $\delta^{15}N$ values above +3 ‰ then manuring is indicated) save for the emmer wheat from Pit 1, in which evenly half of the values indicate manuring whilst the others do not.

From the above, two main observations can be made:

1) Many of the Stensborg cereal crops had been manured.

2) There is intra- and inter-species variation in manuring.

The data demonstrate that the manuring of cereal crops was practiced in the EN in southern Scandinavia. At the most basic level, this demonstrates that EN farmers practiced an integrated regime of livestock and cereal-based agriculture. Both varieties of wheat from all contexts were consistently manured in this sample. Barley, conversely, indicates manuring inconsistently between contexts. The presence of non-manured barley within the same pit as manured bread wheat and manured emmer wheat (Pit 1) demonstrates that barley and wheat varieties were grown in separate plots, at least some of the time.

The observed specific differences in manuring might be explained by differential manuring needs of the species and the plants' overall hardiness. Wheat, in general, requires more manure to achieve maximum yields regardless of the previous year's land-use than does barley (Cooke 1982). However, barley can better accommodate adverse growing conditions (Bogaard et al., 2013). Manure availability is influenced by several factors, including numbers of livestock, applied husbandry strategies, and what proportion of manure was collected. If, for example, cattle were grazed further afield in grasslands or other natural environments in the summer months, which dietary isotopes in EN cattle in part show (Gron and Rowley-Conwy, 2017), then manure collection may have only been practicable some of the time.

We also do not know how many cattle or other livestock an individual farm would have had and the faunal record offers little elaboration. In eastern Sweden, TRB faunal assemblages from sites yielding domestic species are generally small, and the material is often burned. The absolute largest faunal assemblage is from Anneberg, near to Uppsala today, but this is dominated by fish and marine mammals with many fewer domestic species (Segerberg 1999). The largest assemblage of domestic species, and likely the best view of farming in the area, is from Skumparberget, some 100 km west of Stockholm, but even this bone material contains a NISP of fewer than 400 for cattle (Hallgren, 2008). These assemblages are hardly interpretable with regards to how many livestock were raised at a given time.

Under limited manure supply, which is assumed for Neolithic northern Europe (Bogaard, 2012), differentially-responding crops were likely prioritized by their response to such a limited resource. If so, we expect wheat species to have been prioritized over barley, as barley is the hardier of the species. This is consistent with the data, suggesting that manure was a limited resource.

We envisage that the wheat and barley samples indicating medium levels of amendment (following Bogaard et al., 2013) were most likely to have been grown in relatively small plots, corresponding to the emerging view of intensive garden agriculture undertaken by the first farmers in northern Europe in the early Neolithic (Bogaard, 2004, 2012; Bishop et al., 2009; Whitehouse et al., 2014). The palynological record indicates little forest clearance or widespread cereal cultivation in the earliest Neolithic in southern Scandinavia (Schrøder et al., 2004; Rasmussen, 2005; Regnell and Sjögren, 2006; Lagerås, 2008), but domesticated cattle were being fed in open environments, some of which were anthropogenic in formation (Gron and Rowley-Conwy, 2017). This indicates that farming was likely being performed on a small-scale in forest clearings. The barley grains from the two pits indicating low or no manuring are intriguing within this wider research context and indicate crops being grown in different conditions to those found in these small intensively managed plots that were presumably located very close to domestic settlements (Jones 2005). Further isotopic research on archaeobotanical assemblages and detailed geoarchaeological analysis of contemporary palaeosols is needed to explore this idea further.

4. Conclusions

Our results demonstrate that the manuring of crops was a feature of early Neolithic agriculture in southern Scandinavia, as part of an integrated regime of cereal cultivation and livestock husbandry. These data challenge the idea that systematic manuring only started occurring in Sweden once byres became incorporated into houses during the Bronze Age, thus facilitating the collection of manure (Viklund 1998; Robinson, 2003). We suggest that manure was indeed in limited supply as is often supposed for Northern Europe (Bogaard, 2012), probably owing to limited numbers of livestock and variable seasonal husbandry strategies. Collected from a limited number of livestock, available manure was selectively applied to wheats preferentially over barley in consideration of their responses to manuring, as well as the ability of barley to produce yields without soil amendment.

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Sample Numbers	Pit Number	Species	Number of Grains (N)	Mean δ15N	Std Dev δ1
ST IS.61-70	1	Bread Wheat	10	4.61	2.21
ST IS.21-30	1	Emmer Wheat	10	3.86	1.95

ST IS.1-10	1	Naked Barley	10	2.39	2.43
ST IS.71-80	2	Bread Wheat	10	3.66	2.52
ST IS.31-40	2	Emmer Wheat	10	4.33	2.17
ST IS.11-20	2	Naked Barley	10	3.56	1.23
ST IS.51-60	2/3	Naked Barley	10	2.12	2.91
ST IS.41-50	3	Emmer Wheat	10	3.74	1.25

Table 1: Summary Data. Percent of grains in manured range (>3 ‰) as per Bogaard et al. (2013).

Supplementary Tables

Sample Number	Pit Number	Species	Grain Form	Preservation	X (mm)
ST IS.1	1	*Hordeum* sp. var. nudum	symmetric	P3	5.8
ST IS.2	1	*Hordeum* sp. var. nudum	asymmetric	P2	5.1
ST IS.3	1	*Hordeum* sp. var. nudum	asymmetric	P2	5.3
ST IS.4	1	*Hordeum* sp. var. nudum	asymmetric	P3	4.6
ST IS.5	1	*Hordeum* sp. var. nudum	asymmetric	P2	5.6
ST IS.6	1	*Hordeum* sp. var. nudum	asymmetric	P2	5.4
ST IS.7	1	*Hordeum* sp. var. nudum	symmetric	P3	4.8
ST IS.8	1	*Hordeum* sp. var. nudum	asymmetric	P2	4.5

ST IS.9	1	*Hordeum* sp. var. nudum	symmetric	P2	5.0
ST IS.10	1	*Hordeum* sp. var. nudum	asymmetric	P2	5.3
ST IS.11	2	*Hordeum* sp. var. nudum	asymmetric	P3	4.9
ST IS.12	2	*Hordeum* sp. var. nudum	symmetric	P2	3.6
ST IS.13	2	*Hordeum* sp. var. nudum	asymmetric	P2	4.3
ST IS.14	2	*Hordeum* sp. var. nudum	symmetric	P2	4.4
ST IS.15	2	*Hordeum* sp. var. nudum	asymmetric	P2	3.6
ST IS.16	2	*Hordeum* sp. var. nudum	asymmetric	P2	3.5
ST IS.17	2	*Hordeum* sp. var. nudum	symmetric	P3	4.8
ST IS.18	2	*Hordeum* sp. var. nudum	symmetric	P2	4.1
ST IS.19	2	*Hordeum* sp. var. nudum	symmetric	P3	4.2
ST IS.20	2	*Hordeum* sp. var. nudum	asymmetric	P3	3.8
ST IS.21	1	*T. dicoccum*		P3	4.6
ST IS.22	1	*T. dicoccum*		P2	3.7
ST IS.23	1	*T. dicoccum*		P2	4.6
ST IS.24	1	*T. dicoccum*		P2	4.0
ST IS.25	1	*T. dicoccum*		P2	4.2
ST IS.26	1	*T. dicoccum*		P3	4.5
ST IS.27	1	*T. dicoccum*		P3	3.8
ST IS.28	1	*T. dicoccum*		P3	4.2
ST IS.29	1	*T. dicoccum*		P2	4.5
ST IS.30	1	*T. dicoccum*		P2	3.9
ST IS.31	2	*T. dicoccum*		P3	5.0
ST IS.32	2	*T. dicoccum*		P2	4.0
ST IS.33	2	*T. dicoccum*		P3	4.2

ST IS.34	2	*T. dicoccum*		P3	4.0
ST IS.35	2	*T. dicoccum*		P3	4.5
ST IS.36	2	*T. dicoccum*		P2	4.3
ST IS.37	2	*T. dicoccum*		P3	4.7
ST IS.38	2	*T. dicoccum*		P2	3.7
ST IS.39	2	*T. dicoccum*		P2	5.2
ST IS.40	2	*T. dicoccum*		P3	4.3
ST IS.41	3	*T. dicoccum*		P3	4.1
ST IS.42	3	*T. dicoccum*		P3	4.4
ST IS.43	3	*T. dicoccum*		P3	4.4
ST IS.44	3	*T. dicoccum*		P3	4.4
ST IS.45	3	*T. dicoccum*		P2	4.6
ST IS.46	3	*T. dicoccum*		P3	4.7
ST IS.47	3	*T. dicoccum*		P3	4.7
ST IS.48	3	*T. dicoccum*		P2	3.4
ST IS.49	3	*T. dicoccum*		P3	3.6
ST IS.50	3	*T. dicoccum*		P3	4.0
ST IS.51	2/3	*Hordeum* sp. var. nudum	asymmetric	P3	4.6
ST IS.52	2/3	*Hordeum* sp. var. nudum	asymmetric	P3	5.1
ST IS.53	2/3	*Hordeum* sp. var. nudum	asymmetric	P3	5.6
ST IS.54	2/3	*Hordeum* sp. var. nudum	symmetric	P3	4.6
ST IS.55	2/3	*Hordeum* sp. var. nudum	asymmetric	P3	5.0
ST IS.56	2/3	*Hordeum* sp. var. nudum	symmetric	P2	5.7
ST IS.57	2/3	*Hordeum* sp. var. nudum	asymmetric	P3	5.1
ST IS.58	2/3	*Hordeum* sp. var. nudum	symmetric	P3	4.1

ST IS.59	2/3	*Hordeum* sp. var. nudum	symmetric	P2	5.7
ST IS.60	2/3	*Hordeum* sp. var. nudum	asymmetric	P2	5.0
ST IS.61	1	*T.* cf. *aestivum*		P2	3.7
ST IS.62	1	*T.* cf. *aestivum*		P3	4.2
ST IS.63	1	*T.* cf. *aestivum*		P2	3.7
ST IS.64	1	*T.* cf. *aestivum*		P2	3.6
ST IS.65	1	*T.* cf. *aestivum*		P3	4.0
ST IS.66	1	*T.* cf. *aestivum*		P2	3.7
ST IS.67	1	*T.* cf. *aestivum*		P3	3.7
ST IS.68	1	*T.* cf. *aestivum*		P3	3.6
ST IS.69	1	*T.* cf. *aestivum*		P2	3.5
ST IS.70	1	*T.* cf. *aestivum*		P3	3.9
ST IS.71	2	*T.* cf. *aestivum*		P2	4.0
ST IS.72	2	*T.* cf. *aestivum*		P3	3.9
ST IS.73	2	*T.* cf. *aestivum*		P3	3.7
ST IS.74	2	*T.* cf. *aestivum*		P3	4.0
ST IS.75	2	*T.* cf. *aestivum*		P2	3.6
ST IS.76	2	*T.* cf. *aestivum*		P3	3.5
ST IS.77	2	*T.* cf. *aestivum*		P2	3.7
ST IS.78	2	*T.* cf. *aestivum*		P3	4.1
ST IS.79	2	*T.* cf. *aestivum*		P2	4.1
ST IS.80	2	*T.* cf. *aestivum*		P3	4.2

Supplementary Table 1: Individual samples, dimensions, and stable isotopic results

Pit Number	**Species**	**Outliers Removed**	**Average δ^{15}N**	**Average δ^{13}C**	**δ^{15}N StDev**	**δ^{13}C**

1	Bread Wheat	ST IS.64, ST IS.70	4.78	-25.15	1.80	0
1	Emmer Wheat	ST IS.27, ST IS.30	3.59	-24.96	1.43	0
1	Naked Barley	ST IS.3, ST IS.4	1.79	-25.58	0.59	0
2	Bread Wheat	ST IS.75, ST IS.77	3.17	-25.54	0.89	0
2	Emmer Wheat	ST IS.32, ST IS.36	4.02	-24.85	1.23	
2	Naked Barley	ST IS.11, ST IS.15	3.67	-25.55	1.01	0
2/3	Naked Barley	ST IS.52, ST IS.59	1.52	-26.72	1.28	
3	Emmer Wheat	ST IS.45, ST IS.50	3.56	-24.98	0.69	0

Supplementary Table 2: Data with δ^{15}N outliers removed. Basis for Figure 2.